First Tracks and initial timing results with the Timepix4 ASIC

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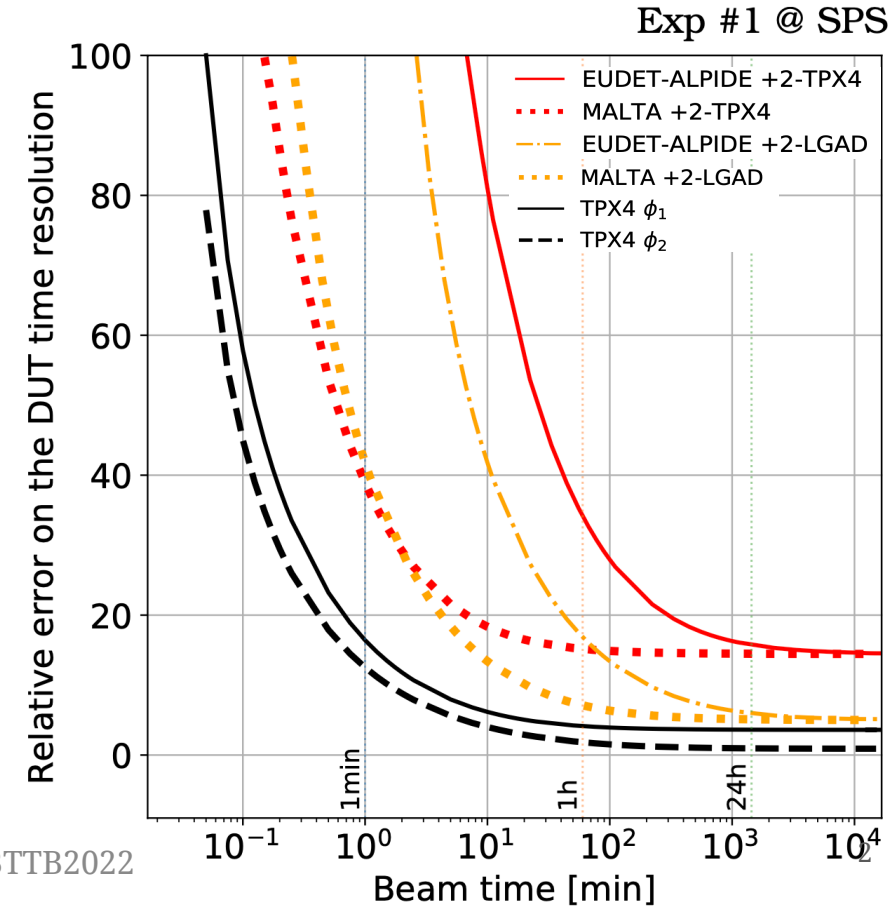
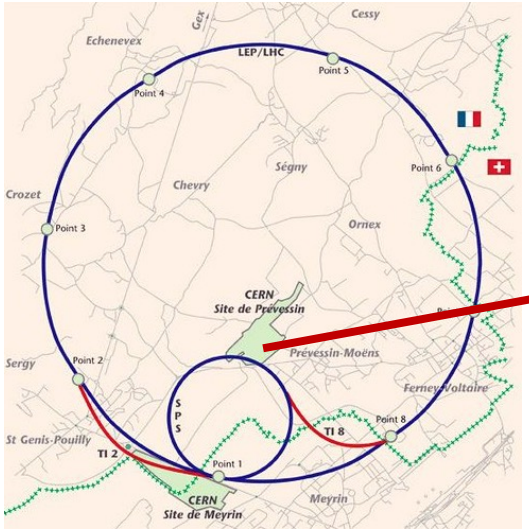
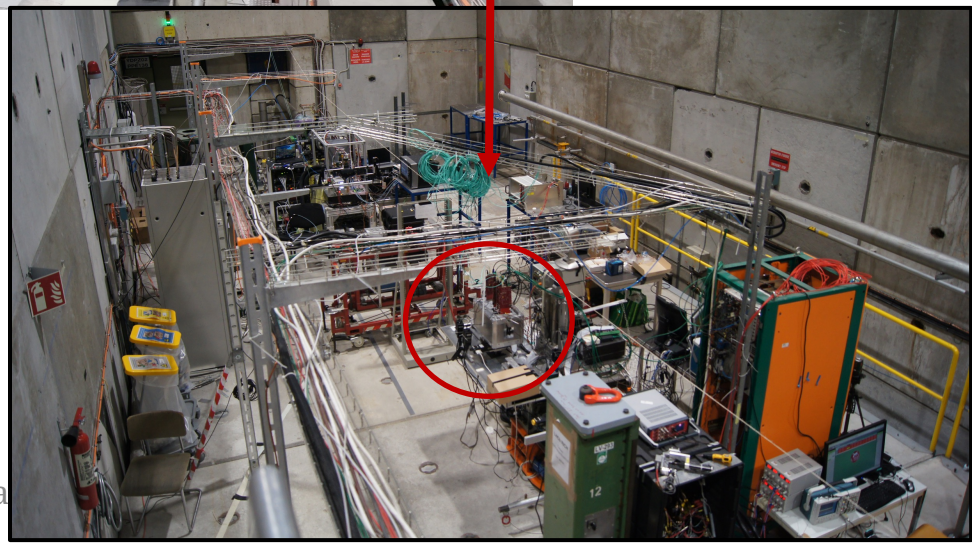
Timepix3 → Timepix4 telescope

- The temporal resolution [1] from Timepix3 yielded an extremely clean clustering and track reconstruction [2] .
- The Timepix4 [3] has 8 times finer TDC and can lead to a real-life 4D tracking device.
  - Can we achieve 20 ps on a track?
- The TPX4 also has a much higher data rate allowing even faster Characterisation of devices [4] – the future 4D detectors need a lot more data!
- As a limited (by parts) test, a **4-layer Timepix4 based tracker was constructed for a testbeam period last October (2021)**

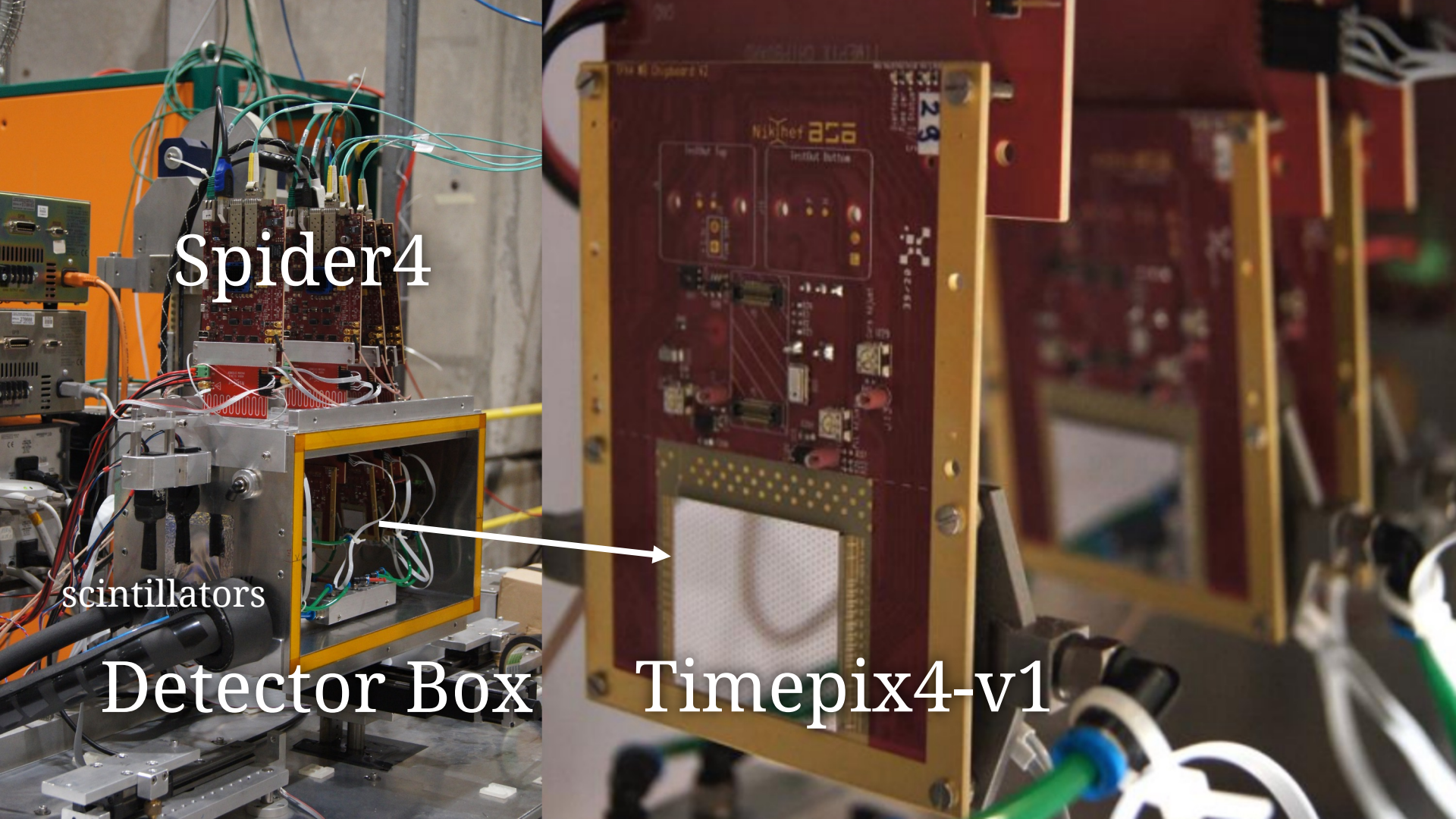


This is not (yet) a Telescope





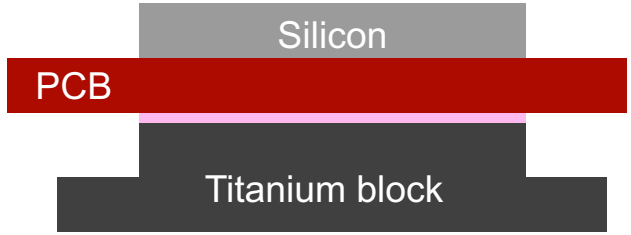
H8 beamline at SPS / CERN
180 GeV/c mixed beam
Mostly pions (K, p)

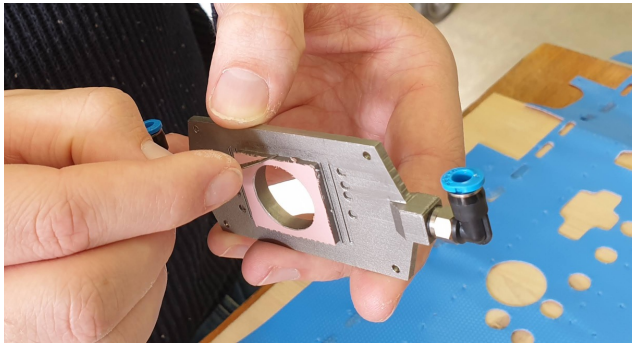

Spider4
scintillators
Detector Box
Timepix4-v1

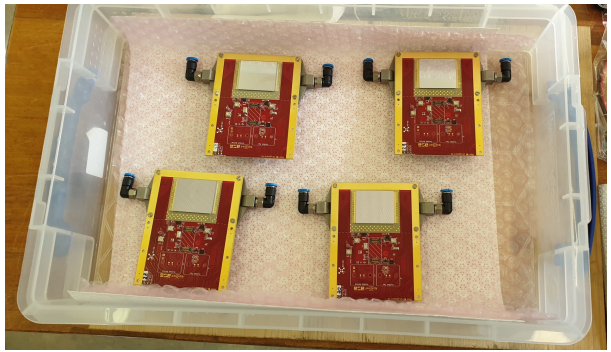
Assemblies and chipboards

- 4 sensors: 2 x 100 µm (timing) and 2 x 300 µm (spatial)
  - All sensors are n-on-p (e^- collecting)
- All chips attached to 3D printed titanium cooling block
- Glycol used to cool chips to about room temperature – ready to go colder

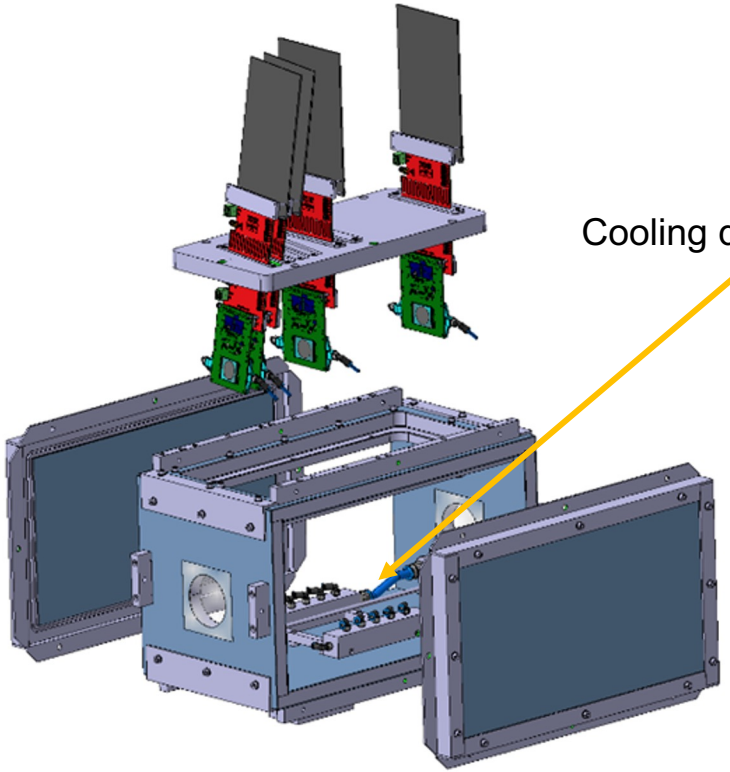
Cooling and interface

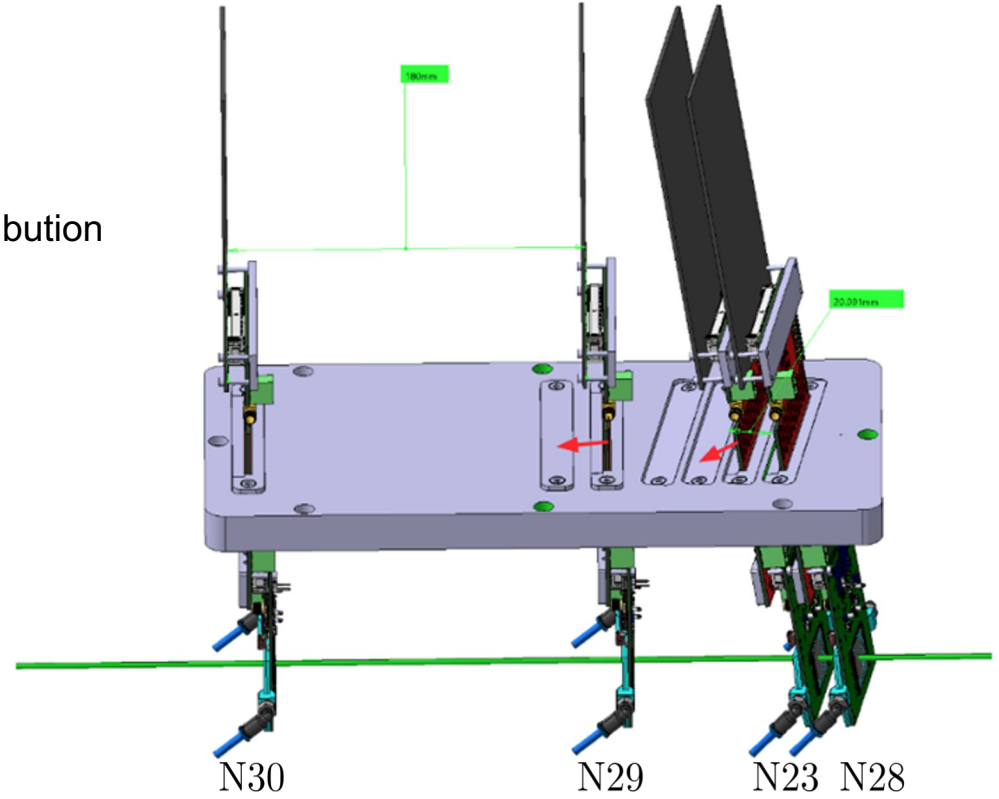




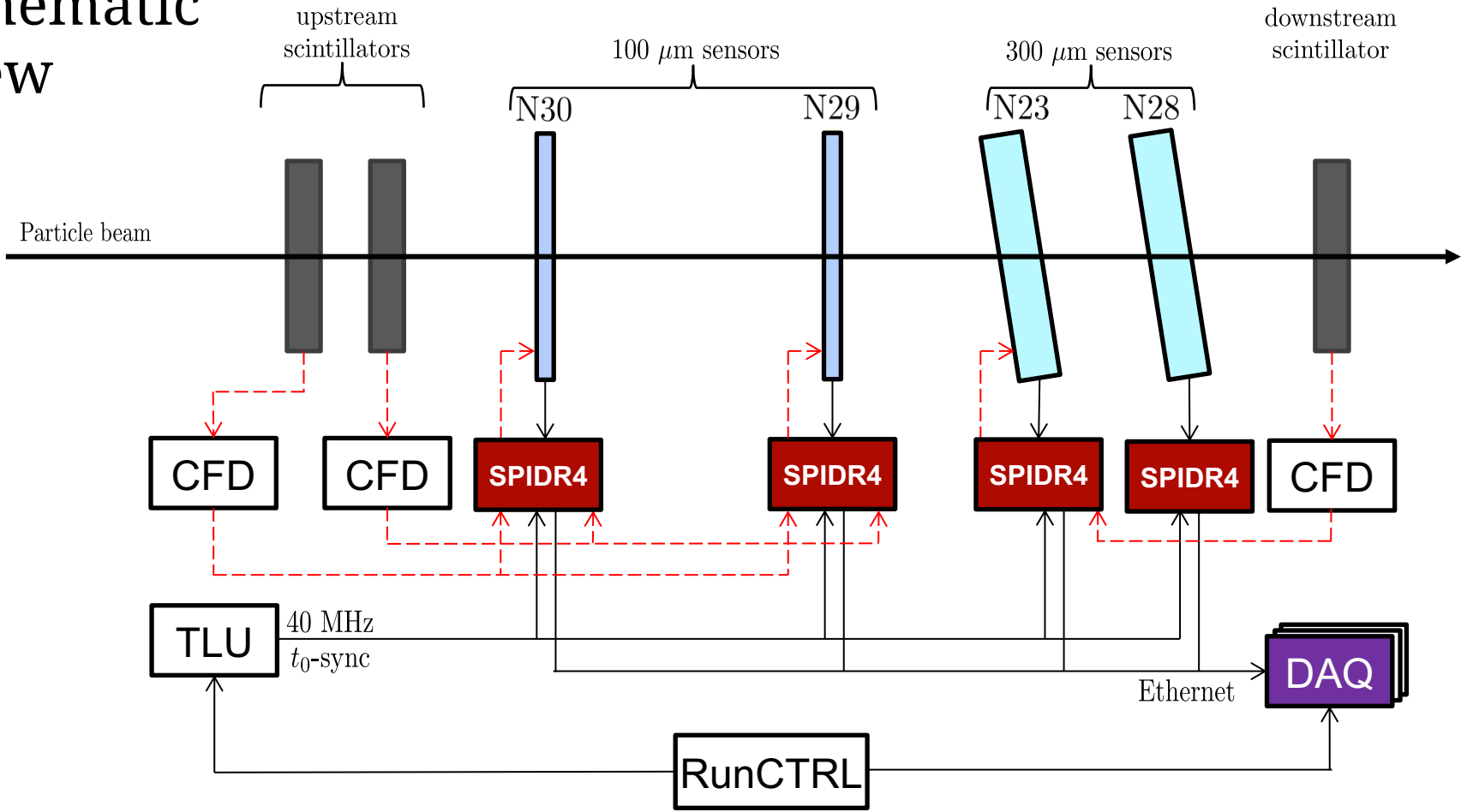


Plane arrangement



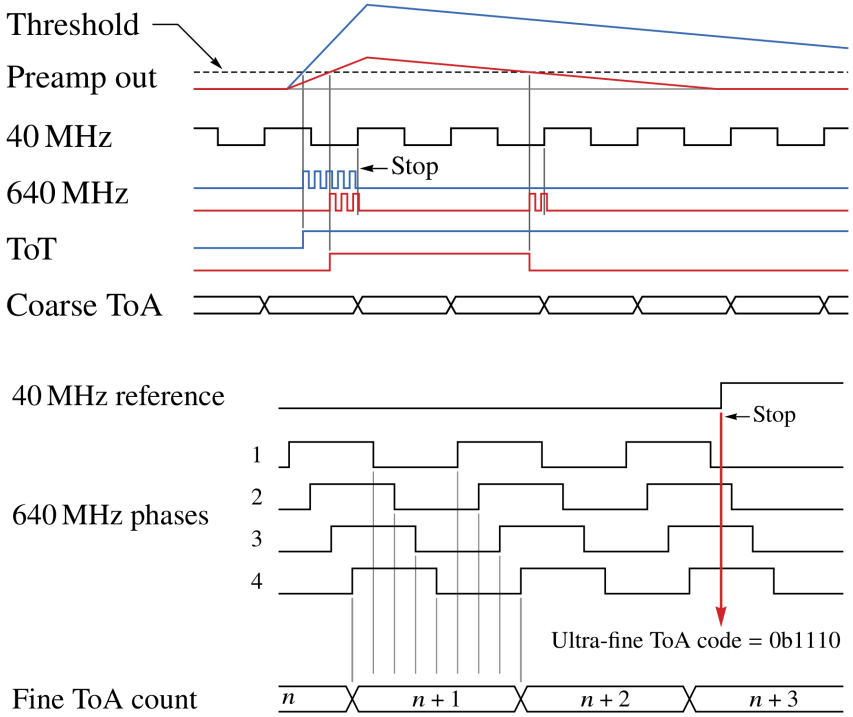


Schematic view



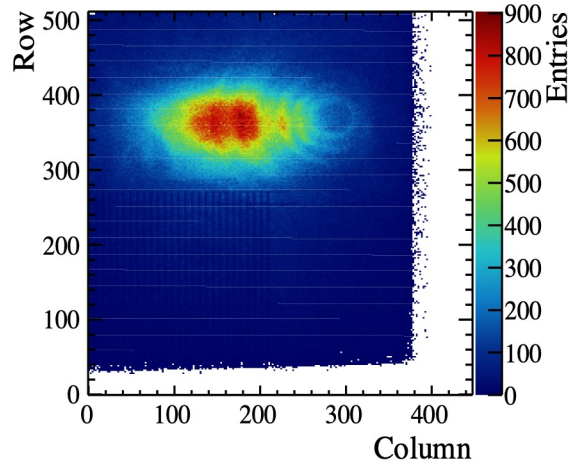
Time measurements in Timepix4

- Base clock of 40 MHz
- Hit starts 640 MHz ring oscillator
  - 1.56 ns bins
  - Count # clock cycles
  - Oscillator shared by 8 pixels in superpixel
- Oscillator is stopped by first rising edge of 40 MHz clock
- In addition, the internal state of ring oscillator is captured → 195 ps bins
- Total Time-Over-Threshold is also recorded – Proportional to the energy deposited.

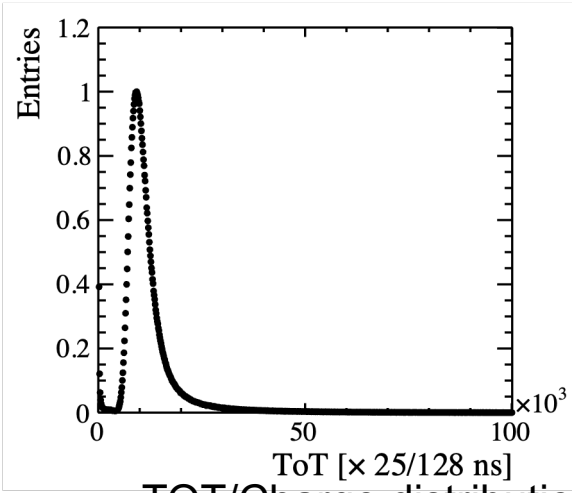


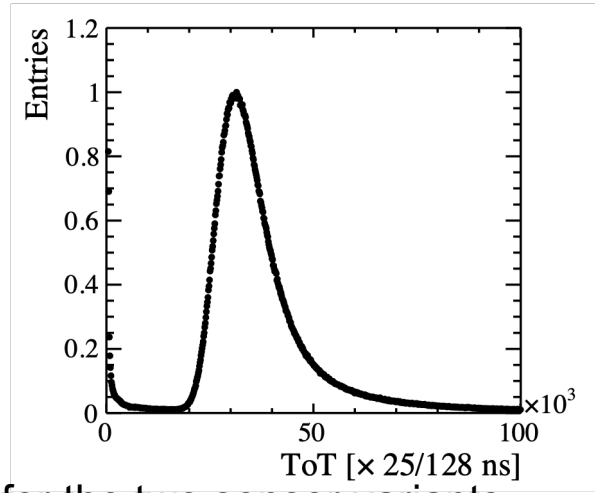
Data Analysis and Results

- Online monitoring to check for performance
- ToT and hitmap look “as expected”
- Offline analysis using the LHCb’s Kepler framework.



Hitmap of associated clusters to a track on a single plane





TOT/Charge distribution for the two sensor variants

Nikhef

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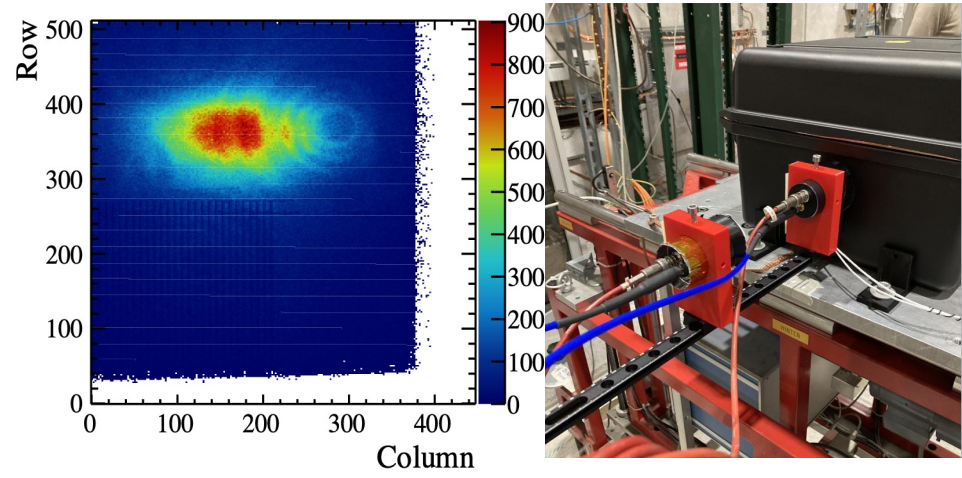

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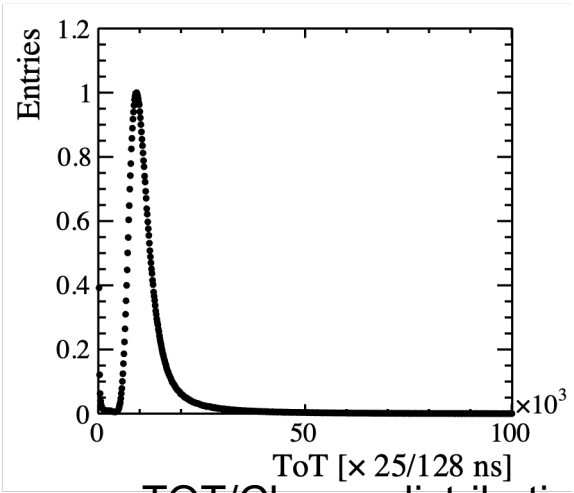

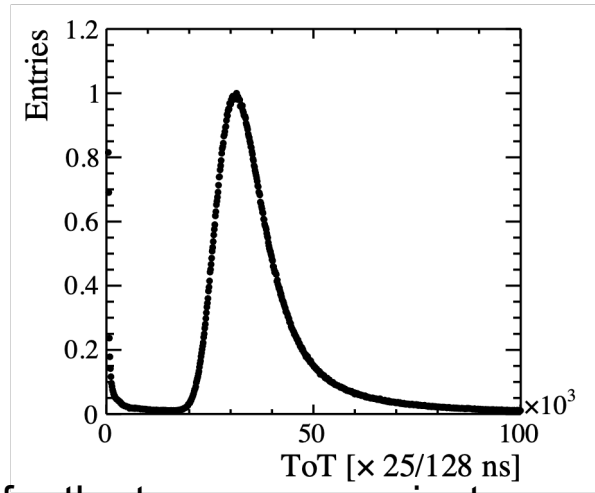

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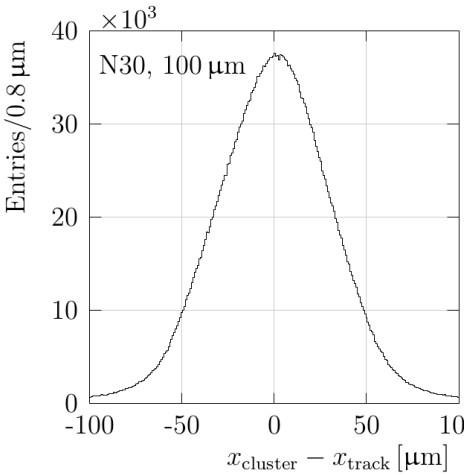
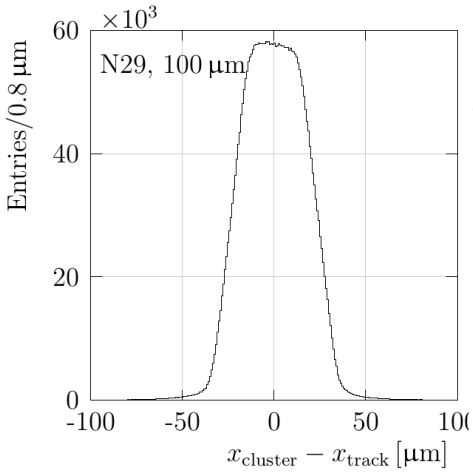
Nikhef

Spatial Residuals

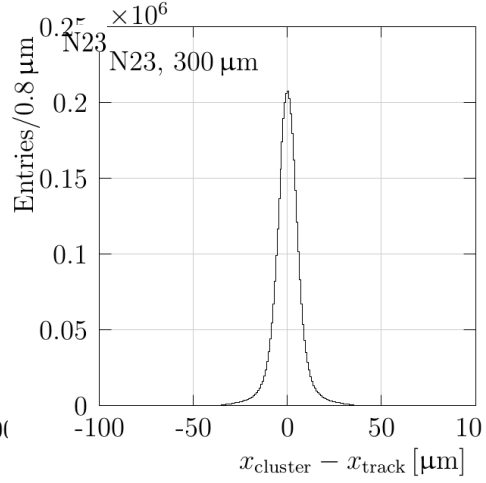
$\sigma = 33\ \mu m$



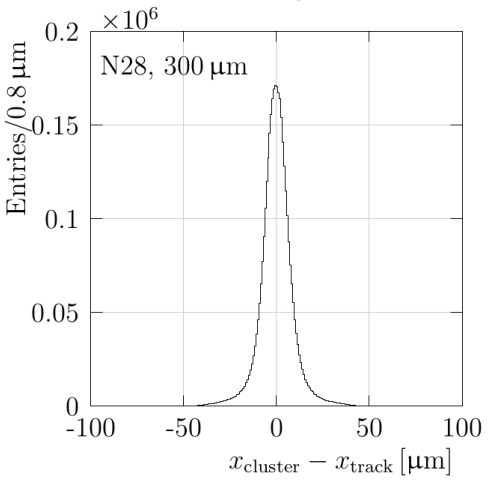
$\sigma = 17\ \mu m$



$\sigma = 7\ \mu m$



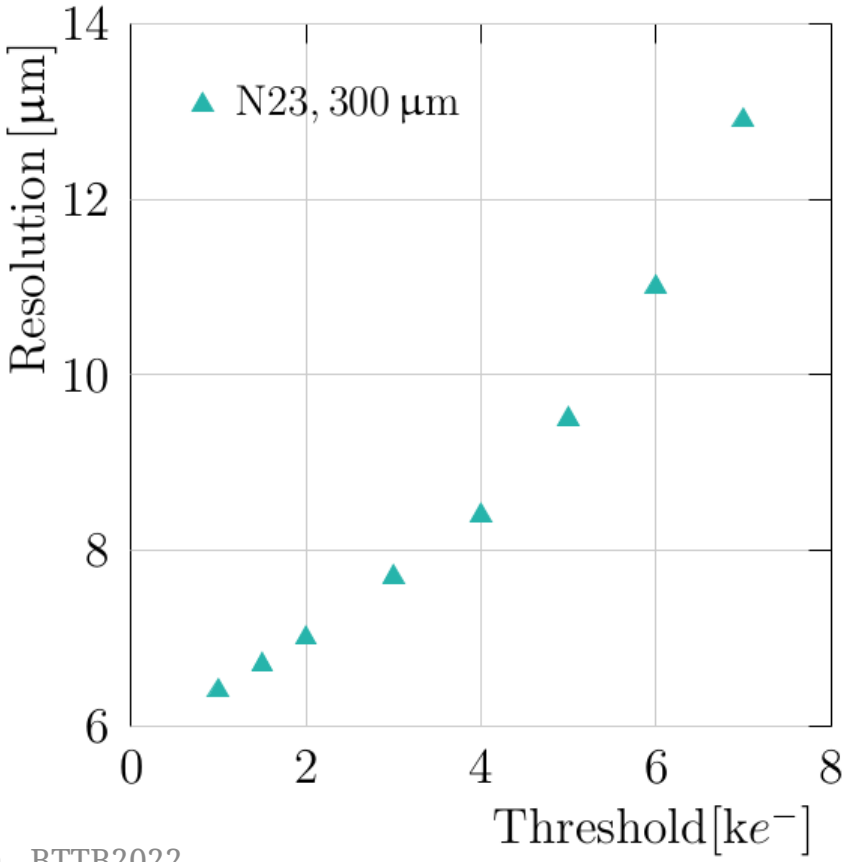
$\sigma = 9\ \mu m$



The pointing resolution is not subtracted from these values, hence the huge differences

Spatial Resolution

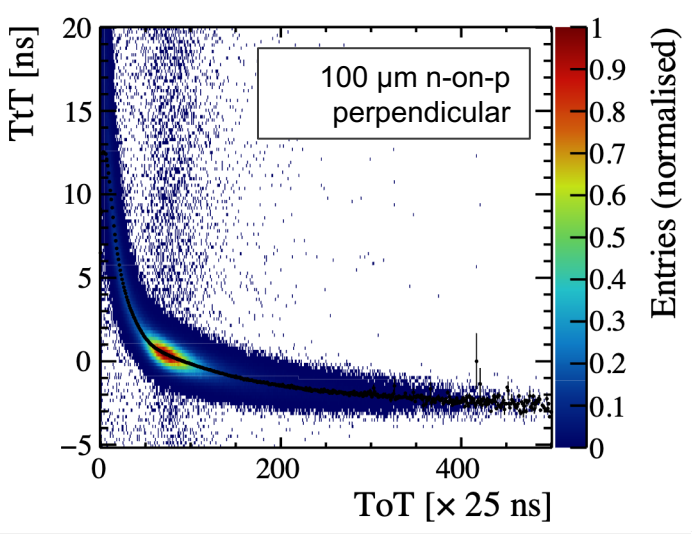
Spatial resolution as a function of the applied threshold for a 300 µm sensor.

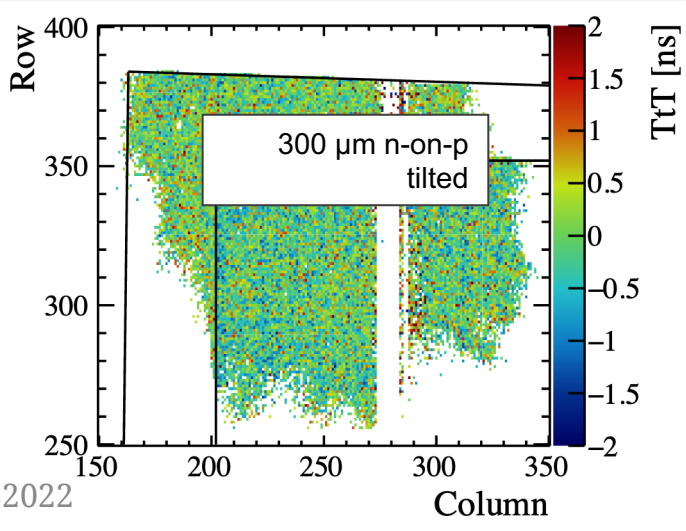


Timing corrections

- A mip typically gives a signal of 2 (6) μs in TOT, equivalent to 7.5k (22k) e, or 1.3 (4) fC for a 100 (300) μm sensor.
- no calibration yet for TOT to charge.

- Timewalk correction applied using Time-to-Threshold (TtT) measurements
  - Track based timewalk correction for tilted sensors





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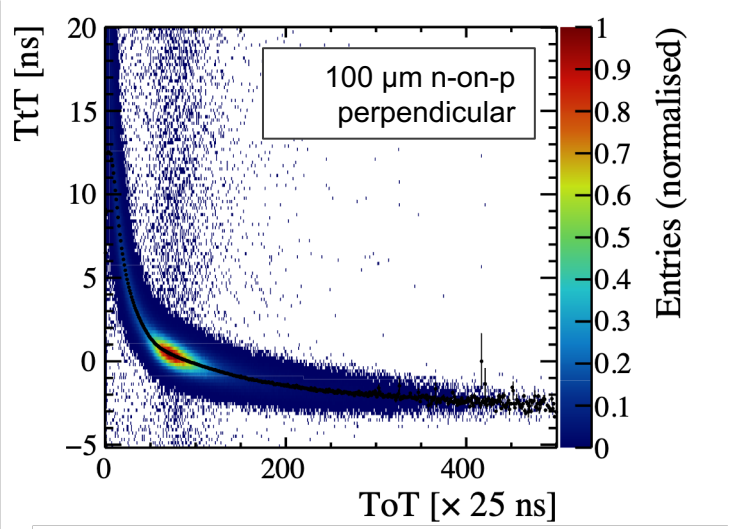
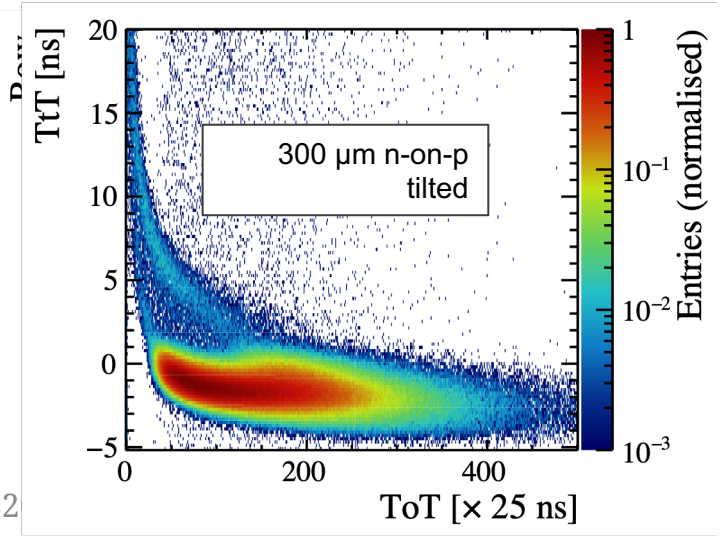
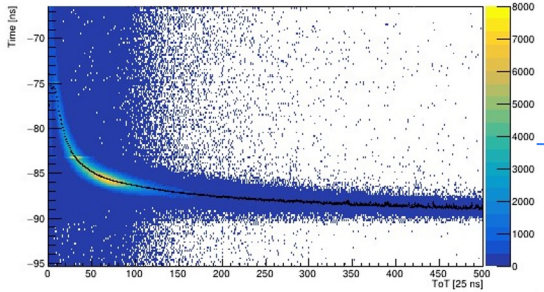




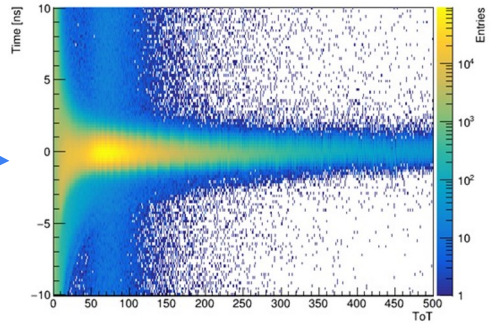
Timing corrections

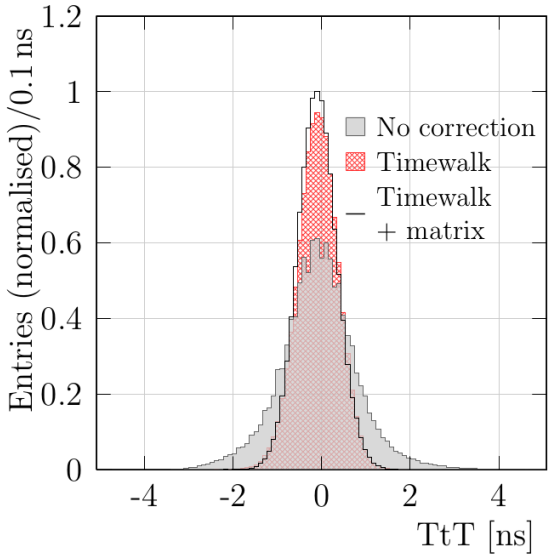
- Track resolution, at nominal threshold and highest bias voltage: 340 ps

before



after



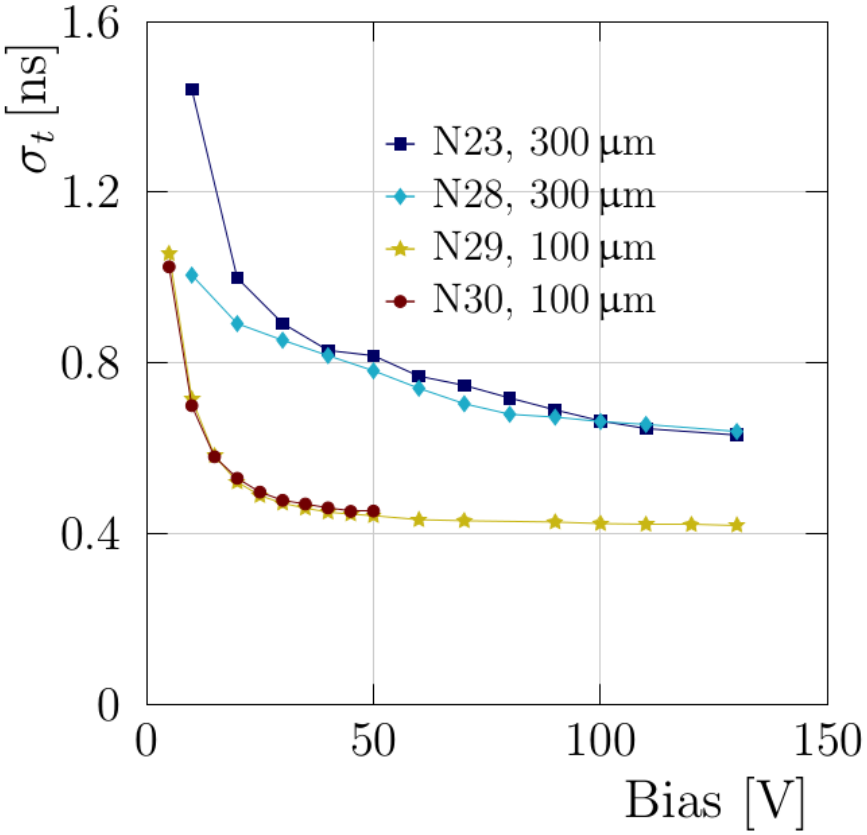


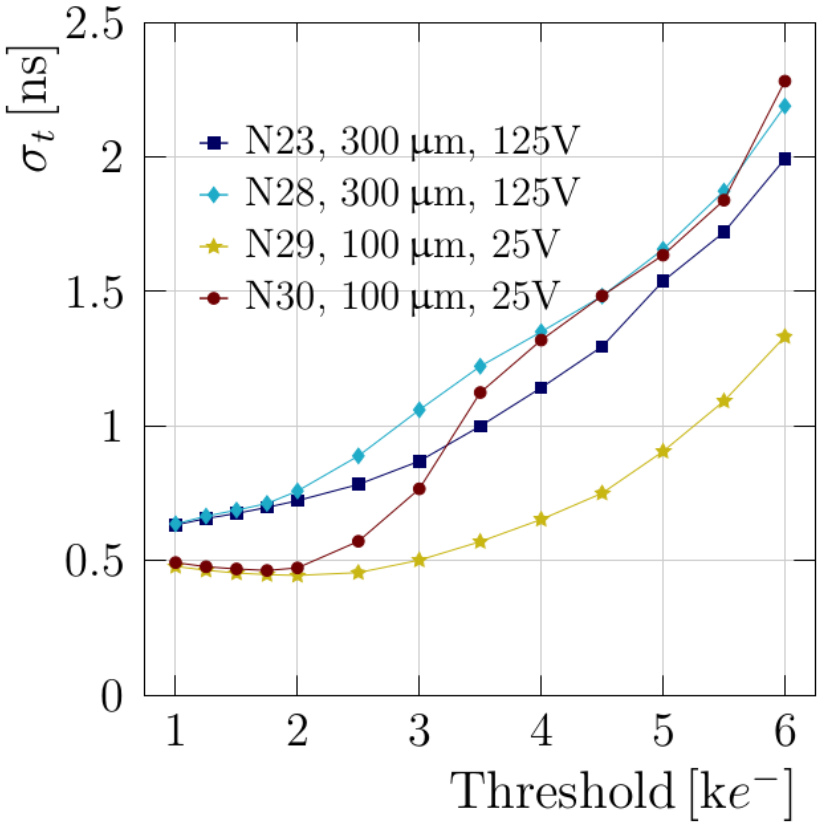
Temporal Residuals

Corrections:	σ_t [ps]
None	789
Timewalk	450
Timewalk + delay offset	439

An example of the corrections: 100 µm n-on-p @ 50 V

Temporal resolutions



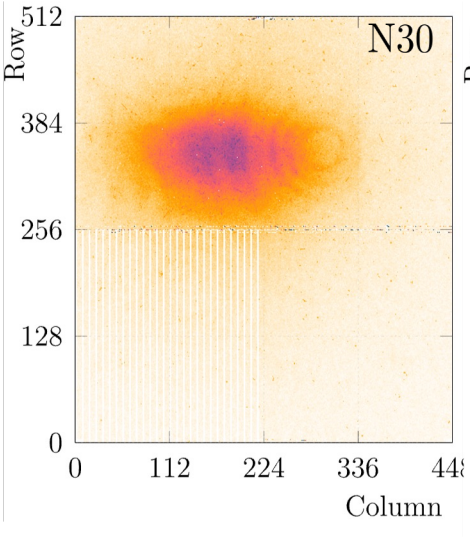


Threshold dependency [5]

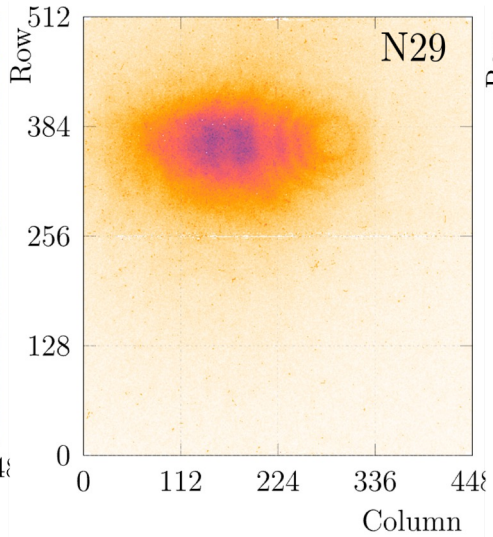
Summary and Outlook

- First results 4-layer tracker constructed with Timepix4 ASICs.
- Initial analysis provides track and time resolution indications
- Planning runs with full, 8-layer, telescope in 2022
  - Additional SPIDR4 systems and sensors
  - First attempt to run with Timepix4v2
  - Improve the time resolution of reference signal
    - MCPs + PicoTDC – <20 ps?

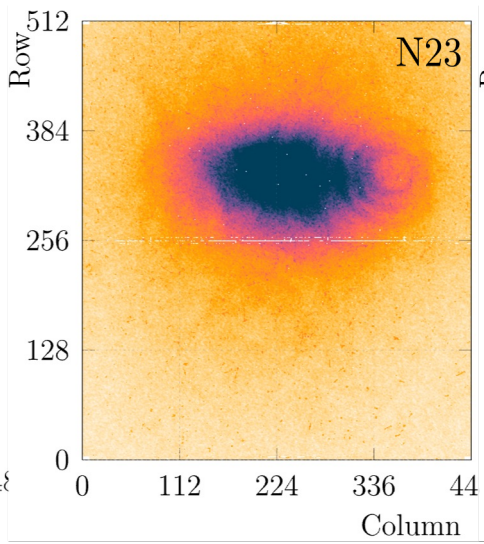
Efficiencies



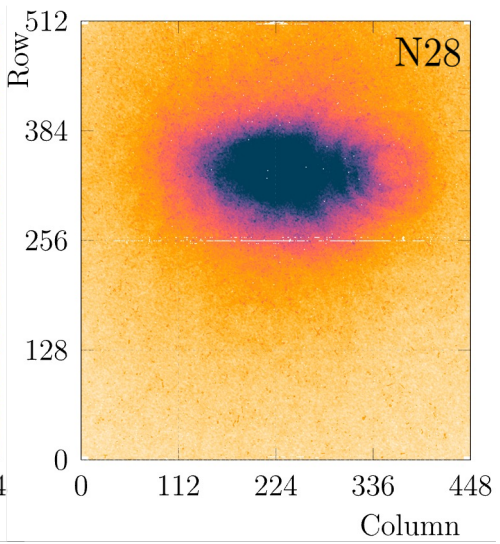
$\varepsilon = (92.0 \pm 5.0)\%$



$\varepsilon = (99.1 \pm 0.4)\%$



$\varepsilon = (98.2 \pm 0.3)\%$



$\varepsilon = (99.4 \pm 0.2)\%$

Timepix3 → Timepix4

			Timepix3 (2013)	Timepix4 (2019)
Technology			130nm – 8 metal	65nm – 10 metal
Pixel Size			55 x 55 µm	55 x 55 µm
Pixel arrangement			3-side buttable 256 x 256	4-side buttable 512 x 448
Sensitive area			1.98 cm^2	6.94 cm^2
Readout Modes	Data driven (Tracking)	Mode	TOT and TOA	
		Event Packet	48-bit	64-bit
		Max rate	0.43x10^6 hits/mm^2/s	**3.58x10^6 hits/mm^2/s**
		Max Pix rate	1.3 KHz/pixel	**10.8 KHz/pixel**
	Frame based (Imaging)	Mode	PC (10-bit) and iTOT (14-bit)	CRW: PC (8 or 16-bit)
		Frame	Zero-suppressed (with pixel addr)	Full Frame (without pixel addr)
		Max count rate	~0.82 x 10^9 hits/mm^2/s	~5 x 10^9 hits/mm^2/s
TOT energy resolution			< 2KeV	**< 1Kev**
TOA binning resolution			1.56ns	**195ps**
TOA dynamic range			409.6 µs (14-bits @ 40MHz)	**1.6384 ms** (16-bits @ 40MHz)
Readout bandwidth			≤5.12Gb (8x SLVS@640 Mbps)	**≤163.84 Gbps (16x @10.24 Gbps)**
Target global minimum threshold			<500 e^-	<500 e^-

Timepix3 → Timepix4